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SHIPBOARD HF RECEIVING ANTENNA SYSTEM: DESIGN CRITERIA

W.E. Gustafson and W.M. Chase • Research and Development • 2 June 1970

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PROBLEM

Determine critical factors related to hf receiving-system design, such as antenna coupling and efficiency, multicoupler performance, receiver overload effects, transmitter noise, and atmospheric noise. Relate these factors to arrive at a methodology for evaluation and optimization.

RESULTS

1. Acceptable system sensitivity with several receiving-antenna designs is compromised by the necessity for receiver protection from local transmissions.

2. An R-1051D receiver fed through an AN/SRA-49 multicoupler from a 25-foot trussed whip meets or exceeds sensitivity requirements.

3. Receive-transmit minimum frequency spacing of 2½ percent cannot be provided by this receiving system with an assumed 20 dB antenna decoupling.

4. Although practical isolations with broadband antennas probably preclude 2½ percent minimum frequency separation, comparison of specific antenna designs can be made by using the developed analytical model.

5. With slight increase in frequency-spacing requirements from that with separate antennas, a 2-6 MHz transmitting antenna can be used for reception by decoupling between the antenna bus and the AN/SRA-49 multicoupler.

6. Reception from 6 to 30 MHz on this 2-6 MHz antenna is also possible if directivity and impedance are satisfactory.

7. Decoupling demands may not be consistent with adequate system sensitivity above 6 MHz.

8. Because 5-percent minimum separation to other transmitter frequencies is stipulated, a transmit/receive switch at the transmitter output will also support the receive mode in simplex operation.

9. The best choice from several coupling options for simplex-case reception on the transmitting antenna is controlled decoupling at the transmitter output without additional filtering.

10. Since antenna diversity provides a 3/1 error-rate reduction in copying multichannel broadcast, it is important that design options provide more than one receiving antenna.

RECOMMENDATIONS

1. Use the results developed here as guidance in designing shipboard receiving antennas and in evaluating proposed designs.

2. Use the results developed here to assess possible improvements in multicouplers and receivers to eliminate deficiencies shown to be of importance.

3. Continue design-feasibility studies at NELC to determine the potential of the combination antenna receive-transmit system (CARTS).

4. Conduct design studies of other common transmit/receive antenna approaches discussed in the report, to determine their technical and operational advantages for simplex operation.

5. Emphasize development and use of multiple receiving-antenna capabilities for antenna diversity applications.

ADMINISTRATIVE INFORMATION

Work was performed under SF 14.222.004, Task 13950 (NELC B164) by members of the Radio Technology Division. The report covers work from October 1969 to April 1970, and was approved for publication 2 June 1970.

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INTRODUCTION

Work has been underway at NELC to develop criteria for antenna system design, for a guide in specific antenna developments. This report covers several aspects of receiving antenna subsystem design, the interdependencies related to specific design choices, and applicable criteria for deriving a near-optimum subsystem design. This work is closely related to current analytical studies under the Shipboard Integrated Electronics System (SIES) program and some of the material used in the report was derived under Task E of the SIES study. The primary emphasis in the report is in the area of antenna-related criteria, but there are several aspects of compatibility involved in antenna and multicoupler design choices. These must be considered when deriving antenna system criteria.

The shipboard environment imposes severe requirements on design of radio frequency (rf) portions of the hf communications complex. The space generally available for antennas is amidships and covers a length of only about 200 to 300 feet. Design of the 2-32 MHz portion of the communications suit (referred to as hf) must take into account that this very limited area is about one-half wavelength in extent at 2 MHz. Spacings from major ship structures that act as parasitic radiators are very small and this results in major coupling problems. Coupling between the numerous communications antennas that must be placed in this small area is very high. This leads to particularly difficult problems in receiving-system design because of the very large voltages that exist on receiving antennas as a result of the nearby transmitting antennas. Levels up to 100 volts can be expected and must be allowed for in protecting the receiving system from burnout and from other degrading phenomena such as overload desensitization, cross-modulation, and intermodulation.

Some idea of the design difficulty can be obtained from comparing the normal receiving-system threshold to transmitter power levels. Typical transmitter power levels are 1 kW (30 dBW) while typical receiving threshold is about 1 microvolt (-137 dBW). This leaves a differential of 167 dB. The small area leads to a nominal transmit-to-receive antenna isolation of about 20 dB.if care is taken to most effectively use the available space. Even with separate antennas the power differential is 147 dB. The receiving system must operate with this very great power differential. Receiver parameters related to interfering signals are usually stated in terms of 0.1 to 1.0 volt while expected levels on the receiving antenna are 10 to 100 volts. Much additional filtering is required to reach a tenable design, and this is usually obtained in the receiving multicoupler.

There are other factors related to receiving-system design, such as intermodulation, expected atmospheric noise level, transmitter noise and spurious signal levels, and receiver spurious responses. All of these affect to some degree the design requirements for receiving antennas. It is the purpose here to discuss receiving-antenna design approaches in relation to the complex dependencies of the above factors. The design compromises will be discussed in quantitative terms in an attempt to provide design guidance for future development work and for antenna systems design. Transmitter noise was not included, since there is a possibility of reducing this noise through redesign or modification. It was considered unwise to allow this deficiency to influence receiving subsystem optimization approaches at this time.

REQUIRED RECEIVING-SYSTEM SENSITIVITY

In hf systems design, atmospheric noise is normally the limiting factor in receiving-system capability. This is not necessarily the case in shipboard systems but it is necessary to assess the magnitude of atmospheric noise as one of the limiting factors. This source can then be compared to other potential interference sources to determine the critical one for any specific design approach. The field intensity of atmospheric noise varies with geographical location, frequency, time of day, and season. Means of predicting noise values are contained in reference 1 (see list at end of report).

The large number of possible situations regarding atmospheric noise levels precludes taking into account all of the variables for use in generalized systems design as treated in this report. A different approach is required to reduce the complexity to reasonable bounds. The two major points to be considered are: (1) that atmospheric noise should override receiver noise, i.e., receiving-equipment sensitivity should not be limiting; and (2) that ideally the locally generated interference level should be less than the atmospheric noise level so as not to place further restrictions on system sensitivity. In either case the most difficult situation is that for very low atmospheric noise levels. However, to design for the lowest possible level expected at any time and at any place results in extreme overdesign and probably cannot be achieved. Accordingly, a compromise position has been established in which quasi-minimum atmospheric noise levels have been determined. Two sources of information were used to derive these values: (1) a comprehensive examination of expected noise at many locations and for all seasons, using data from National Bureau of Standards noise-measurement program; [2] and (2) shipboard measurements in the San Diego area (a typically low-noise region).[3,4] These quasi-minimum values are based on judgement rather than on specific computations and they represent typical low-noise periods in some of the lower noise regions but not in the Arctic. This does not assure that atmospheric noise will not at times drop below receiver noise. There are two reasons for accepting this design compromise: (1) practical limits on receiver, multicoupler, and receiving-antenna noise factors will probably preclude appreciable improvements in system sensitivity; and (2) the fact that atmospheric noise drops lower at times will not compromise system performance for ground-wave propagation and will actually enhance it most of the time. Table 1 lists the quasi-minimum design levels for representative frequencies. It is clear that extreme sensitivity in the receiving system is not required, since a total noise figure of 20 dB at 30 MHz or 52 dB at 2 MHz is tolerable. As will be shown later, this does not mean that very poor receivers are

TABLE 1. QUASI-MINIMUM ATMOSPHERIC NOISE LEVELS, dB ABOVE THERMAL (KTB)

2 MHz	4 MHz	10 MHz	30 MHz
52 dB	42 dB	32 dB	20 dB

acceptable, since filtering required to protect the receivers must use a good portion of this allowable loss budget. Also there is normally insufficient room aboard ship for fully efficient receiving antennas at the lower end of the hf spectrum and some of the loss budget is required to cover this deficiency.

RECEIVING-SYSTEM LOSS BUDGET

RECEIVER SENSITIVITY

It is possible to build hf receivers with a noise figure of 4 to 6 dB when this is the prime requirement. However, aboard ship this is generally not possible because several other factors must be considered in the design and these affect noise figure. The primary factor is that of adjacent strong signal rejection and most shipboard receivers are designed with two tuned stages ahead of the first rf amplifier. This adds loss to the system and results in a practical noise-figure limit of about 9 to 10 dB. When consideration is given to maintainability of good sensitivity in the field, a noise figure of practical design is about 12 dB. Well maintained R-1051/URR receivers now in use have a noise figure of about 12 dB. For purposes of further system computations this value will be used as typical. If results show a significant total system deficiency, the problem of the receiver noise figure will be re-examined to determine the practicability of small improvements in this area. The noise figure as used above is deficient in comparison to that of a perfect receiver operating at room temperature. In other words, a perfect receiver would have a background noise equivalent to thermal noise (KTB).

RECEIVING MULTICOUPLER EFFICIENCY

Receiving multicouplers must provide a high rejection to the high voltages induced by local transmitters. This requires several stages of filtering, and losses increase in proportion to the number of filter stages (assuming a constant ratio of loaded to unloaded Q). It is possible to keep losses lower by using a smaller number of stages and accepting a much larger guard band between transmit and receive frequencies. Alternately, a much larger filter volume will result in lower losses for a given guard band, since losses are inversely proportional to volume (to some power).

The approach used in this design study was to use the current receiving multicoupler series (SRA-38/39/40 and 49) as an example to determine primary design trade-off options. Table 2 lists the insertion loss and off-frequency rejection of these equipments. The higher insertion loss and higher rejection at the lower frequencies reflects an earlier design choice in which it was recognized that some loss of efficiency at the lower frequencies is acceptable because of the generally higher noise as compared to higher frequencies. Also, greater rejection was needed because of more crowding of frequency assignments and greater antenna coupling. These design parameters will be used in a later section to determine possible deficiencies and necessary goals in improving receiving-system design.

TABLE 2. ELECTRICAL CHARACTERISTICS OF AN/SRA-38/39/40 AND -49 MULTICOUPLERS

Frequency (MHz)	Insertion Loss (dB)	Off-Frequency Rejection (dB) 2½% Spacing	5% Spacing
2	15	56	80
4	12	49	73
8	9	43	67
16	8	36	60
30	6	30	54

TYPICAL RECEIVING-ANTENNA EFFICIENCY

Most shipboard antenna-system designs utilize the best space for transmitting antennas, since loss of efficiency results in direct loss of capability. As pointed out above, the receiving system can tolerate a certain amount of loss, and because of this the receiving antennas are generally placed in less favorable locations. In many cases this results in use of a trussed whip or twin whips placed on the stern. Weapons and other system requirements allow typical whip heights of only 25 to 35 feet.

To work out a framework for assessing the relative merit of receiving antenna approaches, the 25-foot trussed whip was chosen as an example. In many cases it is advantageous to use such a whip to cover the 2-30 MHz band by using an AN/SRA-49 multicoupler. Model measurements were used to determine efficiency of such an antenna. Loss due to mismatch was found to be as follows: 2 MHz, 24 dB; 4 MHz, 12 dB; 8 MHz, 2 dB; 16 MHz, 2 dB; and 30 MHz, 2 dB.

SYSTEM LOSS BUDGET

Using the above examples, a loss budget has been worked out for a typical receiving system. Results are shown in table 3. It is evident that

TABLE 3. RECEIVING-SYSTEM LOSS BUDGET

Freq. (MHz)	Loss (dB)				Allowable Total (dB/KTB)
	Receiver*	Multicoupler	Antenna**	Total	
2	12	15	24	51	52
4	12	12	12	36	42
8	12	9	2	23	34
16	12	8	2	22	26
30	12	6	2	20	20

*Receiver noise figure, stated in dB/KTB (thermal noise)

**Antenna assumed to be 25-foot trussed whip

there is not much margin for the configuration used in the example. However, it is believed to be a reasonable compromise solution, considering the difficulty of achieving significant improvements in any of the three possible areas.

Additional margin can be obtained by using a larger receiving antenna for frequencies below 6 MHz. Use of a 50-foot trussed whip would increase the margin by about 12 dB at 4 MHz and below. However, this would impose much greater (if not impossible) design requirements on topside arrangements, and would not improve performance above 6 MHz. Multicoupler loss can be reduced through the use of much larger equipments, but this does not appear to be a feasible approach considering the large number of required filters. Alternatively, fewer filter sections could be used but much poorer performance in other areas would result as will be shown in later sections. It is probable that some improvement can be achieved through redesign of the receiver. It is very likely that use of considerably larger rf tuning components and enclosure can provide an improved noise figure, by possibly as much as 4 dB. This should receive consideration in future receiver designs.

The loss budget in table 3 can be used to assess alternative antenna design approaches by properly taking into account other multicoupler and/or receiver requirements and characteristics. It is not the purpose of this report to discuss details of multicoupler or receiver design alternatives, but examples will be used as required to assure validity of antenna choices. It is planned to publish more details of the antenna-multicoupler-receiver design dependencies in the near future.

RECEIVING ON TRANSMITTING ANTENNA

An alternative design approach is to use transmitting antennas for receiving also. This can be accomplished by decoupling from the antenna coax and using the receiving multicouplers as in the above example (fig. 1).

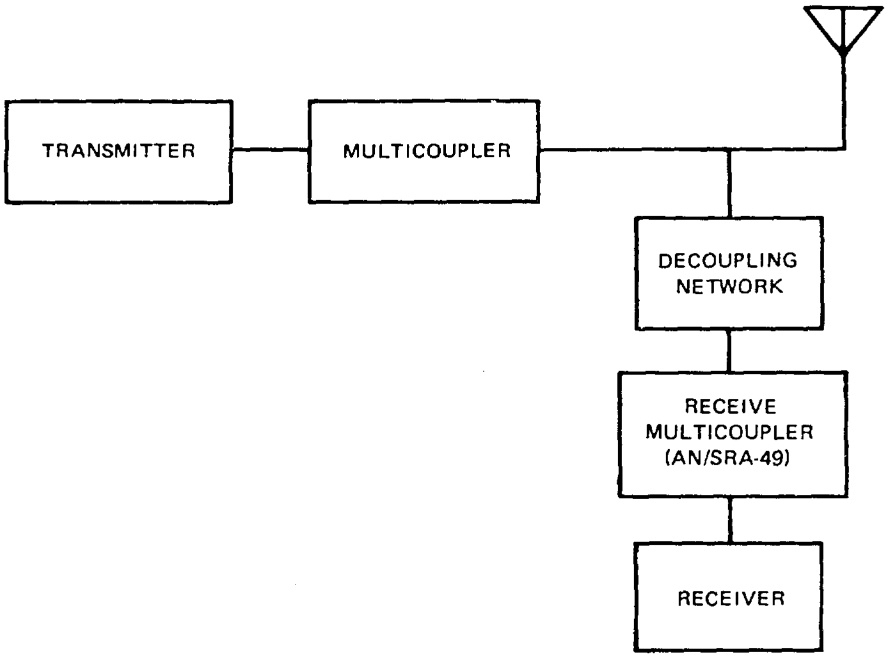


Figure 1. Common transmit/receive antenna with decoupling at antenna bus.

There is a requirement that the decoupling network not appreciably affect transmitting-antenna impedance. A separate study is underway at NELC to develop a practical decoupling network and other related design details for a combination antenna receive-transmit system (CARTS). A report covering this work is planned for the near future. Discussions here will not include details of its design but will be limited to power budget and factors related to compatibility when using the common antenna approach.

A primary requirement for a decoupling network is that of assuring sufficient total receiving-system sensitivity. Results of table 3 were used to determine maximum allowable decoupling from the antenna bus in order to just achieve sensitivity goals. Losses in receiver and multicoupler were subtracted from allowable total loss in determining allowable decoupling. Results are as follows: 2 MHz, 25 dB; 4 MHz, 18 dB; 8 MHz, 13 dB; 16 MHz, 6 dB; and 30 MHz, 2 dB. Results to date from the CARTS work indicate that decoupling of 12 dB or more is probably required in order to avoid impedance changes in the transmitting antenna. This applies to the case for receiving and transmitting in the same frequency band. In the case of receiving outside the transmitting band, the primary requirement is that the VSWR not be appreciably changed within the transmitting band. From these general comments it appears that in the 2-6 MHz band it may be feasible to use the common-antenna approach. In the CARTS design, consideration is being given to using the 2-6 MHz transmitting antenna for 2-30 MHz reception, and this probably can be accomplished by allowing a decrease in decoupling above 6 MHz in a controlled manner. There may be a possibility of using a higher frequency antenna for receiving at lower frequencies with a decreased decoupling below its design band. However, it probably will not be feasible to receive and transmit in the same band above about 6 MHz using decoupling at the antenna coax, because allowable decoupling is not great enough.

Another approach for using a common transmit/receive antenna is to couple the receiver to the line between transmitter and multicoupler by using a transmit/receive switch. This is allowable only for simplex operation (transmit and receive alternately on the same frequency). There are a large number of such circuit requirements at hf, particularly below 6 MHz. This is the part of the spectrum where the greatest crowding occurs and it typically presents design problems. Therefore, consideration should be given to using this capability if probable compatibility can be shown. In this approach the loss budget is considerably different, in that the receiving multicouplers may be optional and direct coupling (through the T/R switch) is possible. Figure 2 shows the options that are available.

When coupling at the transmitter, a large part of the off-frequency rejection is achieved in the transmitting multicoupler, since it is tuned to the common transmit/receive frequency for transmitting. The transmitting multicouplers have a typical rejection of about 28 dB at 2½ percent spacing from the adjacent transmitting frequency and about 40 dB at 5 percent. This is much less than the rejection obtained in receiving multicouplers, particularly at the lower frequencies. However, there are design requirements in the case of transmitting multicouplers that preclude operation at frequency spacings less than 5 percent. For this reason the receiver coupled to a transmitting antenna will always be spaced at least 5 percent from the nearest transmitter that is on at the same time. More details of the required rejection will be covered in a later section of this report. In addition to this difference in rejection, the transmitting multicouplers have a much lower insertion loss in the operating passband. This is typically 2 dB instead of the 6 to 15 dB associated with the receiving multicouplers as shown in table 2. Since the transmitting antenna has a mismatch loss of only about 1 dB in its operating band, it is clear that there is a large safety factor in the receiving loss budget when only the transmitting multicoupler is used to protect the receiver. Table 4 shows the loss budget for option No. 3 discussed above, including margin for decoupling in case this is needed. Results show that both multicouplers can be used in tandem up to near 30 MHz in case this is required to protect the receiver. However, as will be discussed later, this may not be necessary or desirable in most cases. In case the receiving multicoupler is

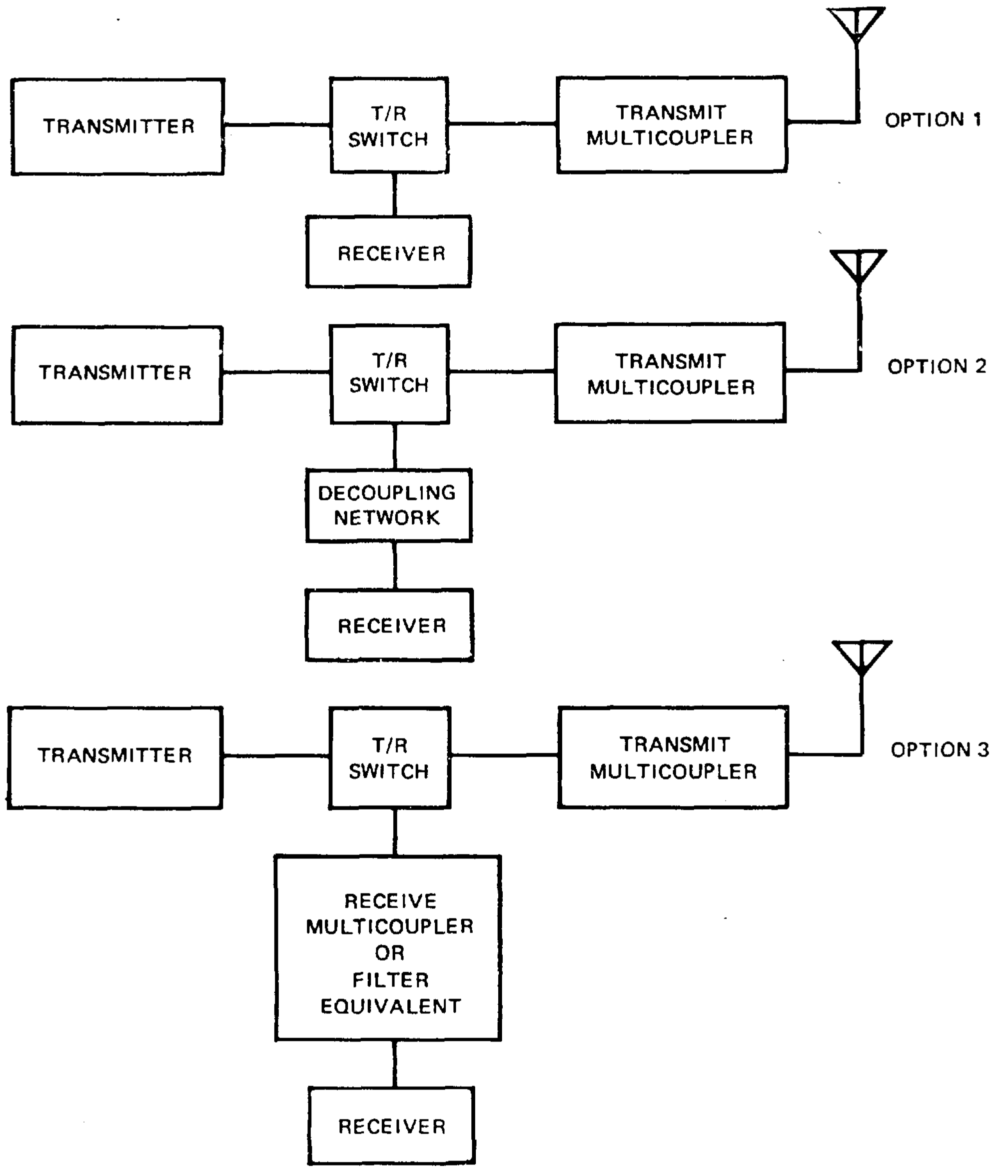


Figure 2. Common transmit/receive antenna with connection at transmitter output.

not required, even more decoupling can be used since the receiving multicoupler loss can be added to the margin. These results indicate that sensitivity should not be a problem in using this approach, and protection of the receiver is the prime consideration.

TABLE 4. LOSS BUDGET FOR RECEIVER COUPLED AT TRANSMITTER OUTPUT

Freq. (MHz)	Allowable* Total (dB)	Transmitting Multi-coupler (dB)	Antenna (dB)	Receiving Multicoupler/Filter (dB)	Margin** (dB)
2	40	2	1	15	22
4	30	2	1	12	15
8	22	2	1	9	10
16	14	2	1	8	3
30	8	2	1	6	-1

*Allowable total from table 3 less 12 dB receiver loss

**Margin for decoupling if both multicouplers are used in series

RECEIVER PROTECTION CONSIDERATIONS

There are several receiver characteristics that are closely related to strong local transmitter interference. All of these are influenced by the amount of filtering placed ahead of the receiver and by the required spacing between receive frequencies and adjacent transmit frequencies. Four of these are: (1) receiver cross-modulation caused by transferring modulation from the interfering signal to a signal on the receive frequency; (2) receiver overload resulting from the receiver's being driven into its nonlinear region by the interfering signal; (3) intermodulation caused by two interfering signals mixing in receiver nonlinearities; and (4) receiver spurious responses. In each case sufficient filtering ahead of the receiver will eliminate the problem, providing the attendant filter insertion loss can be tolerated. As shown in the preceding sections (summarized in table 3), the AN/SRA-49 multicoupler provides a large degree of filtering with insertion loss that is acceptable but with no appreciable margin. It will be used as an example to determine the degree of design difficulty associated with receiver protection. Of course the transmitting multicoupler will be used (with or without receiving multicoupler) for the case of coupling at the transmitter output.

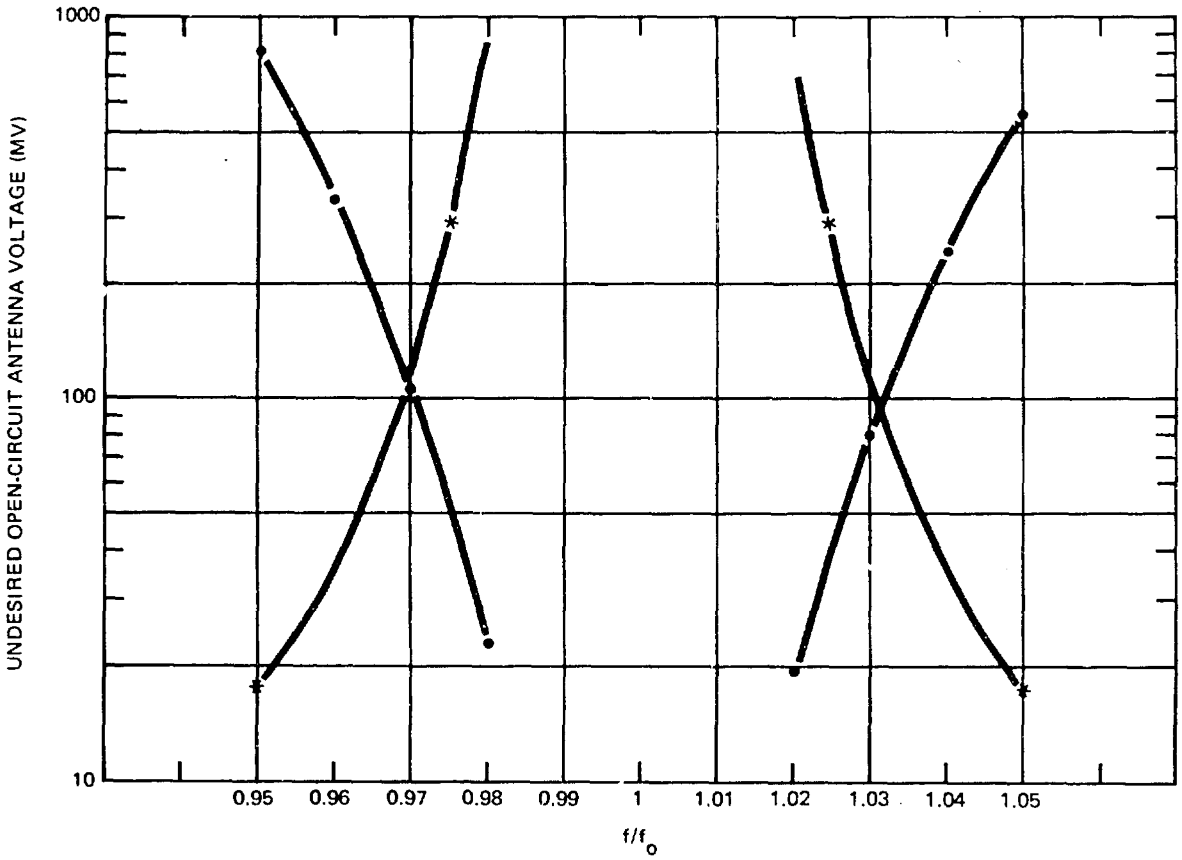
Of the four receiver problem areas discussed above, unreported NELC tests have shown that cross-modulation is typically the most severe. Since this report is concerned with antenna design, discussion will be limited to examination of cross-modulation under the assumption that the other receiver problem areas will be resolved at the same time. This will be discussed in more detail in a subsequent report under another problem. Measurements were made on receiver cross-modulation under another program at NELC and results were used to assess filter requirements. A design goal of 2½ percent spacing between transmit and receive frequencies was assumed. A decoupling factor of 20 dB was assumed to account for the typical shipboard situation without taking into account the very complex decoupling actually existing. Assuming a radiated power level of 1 kW, the open-circuit voltage appearing on a good receiving antenna is expected to be 45 volts, which is 33 dB/1 volt. The multicoupler rejection lowers this voltage by a large amount and expected voltage at the receiver terminals is shown in table 5. Figure 3 is a typical representation of receiver cross-modulation and multicoupler rejection characteristics. The crossover points represent allowable minimum transmit/receive frequency spacings for 1-kW radiated power and 20-dB decoupling. Also

TABLE 5. RECEIVER (R-1051D) CROSS-MODULATION PARAMETERS, SEPARATE RECEIVING ANTENNA

Freq. (MHz)	Open-Ckt. Ant. Volt. (dB/1 V)	SRA-49 Rejection (dB at 2½%)	Receiver Voltage (dB/1 V)	Allowable Volt. at Recv. (dB/1 V at 2½%)	Deficiency (dB)	Allowable Frequency Spacing (%)
2	33	56	-23	-27	4	2.7
8	33	43	-10	-28	18	3.3
24	33	32	1	-29	30	4.1

shown are allowable levels at the receiver and allowable transmit/receive frequency spacing if other than 2½ percent. It is evident that the rejection is marginal at 2 MHz and very inadequate at the higher frequencies. In the absence of improved design it is necessary to increase the spacing from adjacent transmitter frequencies. The SRA-49 has four tuned circuits and the rejection increases rapidly with increased spacing. As a result the required spacing does not increase in proportion to the deficiency shown and the increased spacing may be an acceptable solution. It is apparent that a major improvement in decoupling would be required to meet design goals at 8 MHz and above if the only change made were that of decoupling. It may be possible to improve receiver characteristics but this has not been determined. No appreciable improvement in multicoupler rejection appears feasible since insertion loss is already approaching design limits. As discussed earlier in this report, insertion loss and rejection are interdependent.

The same consideration must be used in assessing feasibility of the common receive/transmit antenna approach. For the case of decoupling from the antenna bus (fig. 1) it was determined that allowable decoupling is 25 dB at 2 MHz, 18 dB at 4 MHz, and 13 dB at 8 MHz. For 2-6 MHz transmitter operation, then, the allowable decoupling will vary between 25 and about 15 dB. This is reasonably close to the nominal 20 dB used in the example for separate receiving antennas, so this approach appears to be acceptable if an increase in spacing can be tolerated (to about 3.3 percent) at 6 MHz. It is evident that operation on higher-frequency transmitting antennas would



• ALLOWABLE UNDESIRED SIGNAL LEVEL FOR R-1051 (DESIRED SIGNAL, 10 μV, 30% MODULATED AT 1000 Hz IN SERIES WITH 50-OHM ANTENNA)

* UNDESIRED SIGNAL 45 VOLTS IN SERIES WITH 50-OHM ANTENNA PLUS COMPUTED AN/SRA-49 FILTER REJECTION (REFERRED TO RECEIVER INPUT TERMINALS)

Figure 3. Receiver-transmitter spacing requirements based on cross-modulation limitations for AN/SRA-49, R1051 receiving system. Receiver tuned to 8 MHz. AN/SRA-49 rejection based on rejection at a tuned frequency of 7 MHz.

require even greater frequency spacings than for the separate receiving-antenna case because of the small allowable decoupling. However, this was found not to be acceptable because of loss-budget problems anyway.

Consideration of the case for coupling in at the transmitter terminals leads to different conclusions, principally because the simplex operation assumed limits spacing to 5 percent or greater. Under this situation the transmit-transmit spacing sets the minimum, which is typically 5 percent. In this case the first rejection is derived from the transmitting multicoupler and, at 5 percent spacing, is about 40 dB over the 2-30 MHz band. The equivalent open-circuit voltage from the interfering transmitter radiating 1 kW is 4.5 volts at the T/R switch point. Table 6 lists pertinent characteristics for cross-modulation when coupling at this point. Results indicate a major deficiency

TABLE 6. RECEIVER (R-1051D) CROSS-MODULATION PARAMETERS, COUPLED AT TRANSMITTER TERMINALS

Freq. (MHz)	SRA-56* Rejection (dB at 5%)	Receiver Voltage (dB/1 V)	Allowable Rec. Volt. (dB/1 V at 5%)	Deficiency (dB)	Allowable Decoupling (dB)	Margin with Decoupling (dB)
2	40	13	-6	19	38	19
8	40	13	-5	18	20	2
24	40	13	-4	17	9	-8

*SRA-56/57/58 series transmitting multicoupler

if no coupling is used and if no receiving multicoupler/filter is used. However, use of a simple deccupling network without receiving multicoupler/filter in series will provide adequate protection up to 8 MHz. (The use of the term multicoupler/filter indicates that a single tunable filter serves each receiver and this is assumed to be equivalent to one port of the SRA-49 receiving multicoupler.) Above 8 MHz the allowable decoupling gradually becomes insufficient and acceptable performance must be obtained by increasing spacing beyond 5 percent or by using the receiving multicoupler/filter in series. As shown in a preceding section this is acceptable from a loss-budget standpoint. With only the allowable decoupling used, the required spacing would increase from 5 percent at 8 MHz to 6 percent at 24 MHz. From these results it appears that, by accepting a small spacing penalty, simplex operation can be used over most, if not all, of the 2-30 MHz range without the use of additional filtering. If transmit-transmit frequency spacings of less than 5 percent were to be used, additional receive filtering would be required. This conclusion entails several other transmitting-system considerations and is not recommended unless detailed analyses of special cases indicate the resulting performance to be acceptable.

MINIATURE RECEIVING ANTENNAS

Another approach to the receiving-antenna design problem is that of tunable miniature antennas. There are two such miniature antennas presently available for use at hf: the AN/SRA-43 for 2-8 MHz operation, developed at NELC, and the AN/SRA-51 for 2-16 MHz, developed by DECO-Westinghouse under Navy contract. Both antennas use short whips, approximately 5 feet long, and are remotely tuned. Each serves only one receiver because of the necessity of tuning to achieve sufficient sensitivity. Analysis of the performance of these antennas is quite complex because their efficiency is greatly influenced by their locations on ship structures. It is not the purpose of this report to assess their effectiveness in any detail, but this general information regarding them is included for completeness.

DIVERSITY-RECEPTION CONSIDERATIONS

A number of investigations have been conducted under other NELC programs[5,6] to determine the merit of diversity reception at hf. These indicate that use of antenna diversity in addition to tone diversity (twinning) in the multichannel broadcast or ship/shore system can provide a reduction of 3/1 to 5/1 in error rate. Tentative results indicate that either polarization diversity or space diversity can provide these gains even within the dimensions available aboard ship. Since the available equipments ashore and aboard ship have this combining capability, it is expected that future ship-antenna designs will be required to address this problem. The alternative receiving-system approaches discussed in this report make it more likely that some diversity capability is achievable. For instance, a stern-mounted, twin-whip antenna could be used in conjunction with a 2-6 MHz transmitting antenna (decoupled for receiving) to provide a space diversity capability. There is an additional diversity action resulting from having noncorrelated azimuthal patterns which should further improve receiving capability. These possibilities indicate the need for determining specific receiving-antenna design feasibility, to allow choices when developing antenna arrangement plans.

CONCLUSIONS

1. Several alternative receiving-antenna approaches provide capability of meeting system-sensitivity requirements. However, when required receiver protection against strong local signals is taken into account, tentative design goals can be met only partially for some options.

2. Use of a 25-foot trussed whip with an AN/SRA-49 receiving multicoupler and an R-1051D receiver will just meet sensitivity requirements at 2 MHz and at 30 MHz with some margin at midband.

3. With an assumed 20-dB decoupling between transmitting and receiving antennas and with equipment listed in (2) above, the goal of 2½ percent spacing between receive and transmit frequencies cannot be met. Required spacing is 2.7, 3.3, and 4.1 percent at 2, 8, and 24 MHz, respectively.

4. It is not probable that the design goal of 2½-percent spacing can be met with broadband receiving antennas by space isolation. However, the analytical model developed in this report will allow assessment of specific antenna designs for such determination.

5. Use of a 2-6 MHz transmitting antenna for receiving appears to be feasible through decoupling at the antenna bus to an AN/SRA-49 receiving multicoupler. Sensitivity requirements can be met over the 2-6 MHz band, with frequency-spacing requirements slightly worse than stated in (3) above.

6. It may be possible to also use the 2-6 MHz antenna for receiving between 6 and 30 MHz providing the antenna has acceptable directivity and impedance characteristics. Separate investigations are being conducted to further determine such feasibility.

7. Decoupling requirements (to achieve acceptable sensitivity) may preclude using the above approach for transmitting antennas above 6 MHz.

8. Use of transmitting antennas for receiving in simplex operation (transmit and receive alternately on same frequency) can be accommodated through coupling the receiver at the transmitter output with a transmit/receive (T/R) switch. In this case, spacing to the nearest other transmit frequency is restricted to 5 percent or more because of transmitting-system requirements.

9. Several coupling options are available for the above simplex case and sensitivity goals can be met with any of them. Other considerations (complexity and frequency spacing) indicate that the probable best choice is that of controlled decoupling without a receive multicoupler/filter in tandem.

10. The options available for receiving-system design are important in providing more than one receiving antenna for use in antenna diversity schemes. Antenna diversity can probably provide at least a 3/1 reduction in error rate.

RECOMMENDATIONS

1. Use the results developed here as guidance in designing shipboard receiving antennas and in evaluating proposed designs.

2. Use the results developed here to assess possible improvements in multicouplers and receivers to eliminate deficiencies shown to be of importance.

3. Continue design-feasibility studies at NELC to determine the potential of the combination antenna receive-transmit system (CARTS).

4. Conduct design studies of other common transmit/receive antenna approaches discussed in this report, to determine their technical and operational advantages for simplex operation.

5. Emphasize development and use of multiple receiving-antenna capabilities for antenna diversity applications.

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UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D		
(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)		
1. ORIGINATING ACTIVITY (Corporate author) Naval Electronics Laboratory Center San Diego, California 92152	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	
	2b. GROUP	
3. REPORT TITLE SHIPBOARD HF RECEIVING ANTENNA SYSTEM: DESIGN CRITERIA		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Research and Development, October 1969 - April 1970		
5. AUTHOR(S) (First name, middle initial, last name) W. E. Gustafson and W. M. Chase		
6. REPORT DATE 2 June 1970	7a. TOTAL NO. OF PAGES 22	7b. NO. OF REFS 6
8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S) 1712	
b. PROJECT NO. SF 14.222.004, Task 13950 (NELC B164)		
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
d.		
10. DISTRIBUTION STATEMENT This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of Naval Electronics Laboratory Center, San Diego, California 92152.		
11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Naval Ship Systems Command	

13. ABSTRACT

A study of critical factors related to hf receiving-system design, such as antenna coupling and efficiency, multicoupler performance, receiver overload effects, transmitter noise, and atmospheric noise.

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Design standards						
High frequency antennas						
Ship antennas						

DD FORM 1 NOV 65 1473 (BACK)
(PAGE 2)

Security Classification